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Effect of Al, Ti and W on microstructure and properties of high tungsten K416B superalloy

Xiang Fei[1, 2], Naicheng Sheng[1, *], Yuping Zhu[1], Jun Xie[1], Jinjiang Yu[1], Guichen Hou[1], Jinguo Li[1], Yizhou Zhou[1], Xiaofeng Sun[1]
1. Shi-changxu Innovation Center for Advanced Materials, Institute of Metal Research, Chinese Academy of Sciences, Shenyang 110016, China
2. School of Materials Science and Engineering, University of Science and Technology of China, Shenyang 110016, China
*Corresponding address: e-mail: nccheng@imr.ac.cn

Abstract

The macro-segregation of W in the K416B alloy ingot has been investigated. It was observed that the distribution of tungsten-rich α-W phases in the ingot is not uniform. And the bottom of the ingot enriched in various shapes and sizes of tungsten-rich α-W phases, consistent with the higher mass fraction of W at the bottom of the ingot. Thermo-Calc thermodynamic software was employed to analyze the influence of major alloying elements on the microstructure of the alloy. The results show that when the content of Al, W and Ti elements exceed certain thresholds, the tungsten-rich α-W phases would be precipitated, and the precipitation temperature and peak content of the tungsten-rich α-W phases increases with the raising content of Al, W, and Ti element. The alloy test rods with different Al and Ti contents were cast at 1550 °C. When the Al content reaches 7 wt. % and the Ti content reaches 2.5 wt. %, the tungsten-rich α-W phase was precipitated in the alloy, and the stress rupture life of the alloy decreases significantly. By adjusting the Al, W, and Ti element contents and casting the alloy ingot of K416B, the macro-segregation of W and Al elements was suppressed. The stress rupture life of the alloy is more than 40 hours, and the fluctuation is small.

Keywords: K416B, α-W, M_6C, the stress rupture life

Introduction

Nickel-based superalloys are the key materials for hot-end components of advanced aero-engines due to their excellent high-temperature mechanical properties, oxidation resistance and hot corrosion resistance [1]. High-W superalloys are strengthened by adding a large amount of solid solution strengthening element W to enhance their high-temperature mechanical properties. The addition of W increases the bonding energy between atoms and affects the distribution of alloy elements between the γ matrix and γ' phase, altering the lattice constants and mismatch of the two phases. W also reduces the stacking fault energy of the alloy and improves its high-temperature strength [2]. K416B alloy is one of the typical high-W superalloys [3], with a W element content of 16 wt. %, which is one of the equiaxed crystals with the highest temperature bearing capacity at present. The addition of a large amount of W element not only strengthens the alloy, but also causes the macro-segregation of W element during the solidification process of the alloy. It is difficult to obtain the alloy with uniform and optimal compositions, which significantly reduces the performance and stability of the alloy. Therefore, studying the phase of tungsten-rich and performance regulation of K416B alloy is crucial for enhancing the performance level of the alloy to ensure the safe and reliable operation of aero-engines.

Experimental procedure

Thermo-Calc software was employed for thermodynamic simulation to investigate the influence of major alloying elements such as Al, Ti and W on the precipitation of the W-rich phase. The test rods of alloy with different contents of Al and Ti were prepared, and the influence of Al and Ti elements on the microstructure and mechanical properties of the alloy were analyzed. By comparing the microstructures and compositions of the alloy ingots at different heights before and after compositional adjustment, the relationship between the tungsten-rich phase and macro-segregation was investigated, and the effect of alloy composition regulation on macro-segregation was verified. The main composition range of K416B alloy is shown in Table 1.

Table 1. Main composition of Alloy K416B (wt. %)

	Al	W	Ti	Cr	Co	Nb	Hf	C	Ni
Upper	5.6	15.3	0.7	4.6	6.0	1.6	0.7	0.08	Bal
Lower	6.2	16.5	1.2	5.2	8.0	2.1	1.2	0.14	Bal

Result and discussion

1. Thermo-Calc calculations

The distribution of element in the ingot would be affected by the precipitation of tungsten-rich phase. Therefore, the solidification process of K416B alloy was simulated by Thermo-Calc, and the effects of Al, W and Ti on the formation of tungsten-rich α-W phase were compared. The results show that when the content of Al, W and Ti exceeds the threshold, the tungsten-rich α-W phase would be precipitated, as shown in Fig. 1. The calculated results are shown in Fig. 1(b-d) for a mere change of Al (W, Ti) elements content while the content of other alloying elements fixed and unchanged. The results indicate that the precipitation of the α-W phase begins when the mass fractions of Al, W, and Ti reach 6.1 %, 15.7 %, and 1.1%, respectively. As the contents of Al, W, and Ti elements increase, the precipitation temperature and peak content of the α-W phase increase.

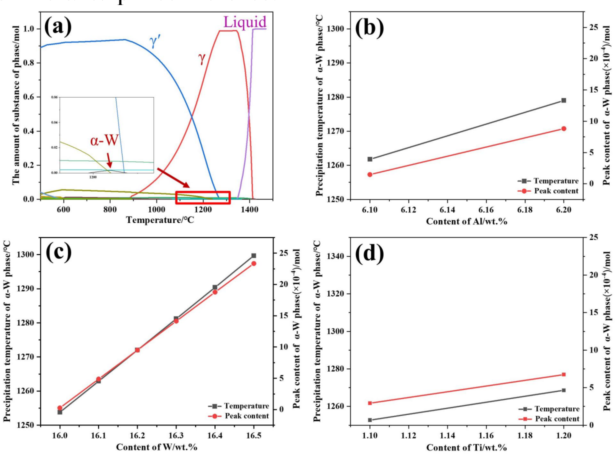

Fig. 1 Thermodynamic calculation results: (a) equilibrium phase diagram of K416B alloy; (b) (c) (d) precipitation temperature and peak content of tungsten-rich α-W phase with different Al, W and Ti contents

2. Distribution of element and microstructure

According to the results of thermodynamic calculations, the alloying elements Al, W and Ti were mainly regulated, and the K416B alloy ingot was recast. The content of elements at different positions of the ingot before and after composition control of the alloy was analyzed and the microstructure was studied, the results are shown in Fig. 2. Before the composition control, the macro-segregation of W and Al elements in the alloy ingot is more significant, and the content of W element at the lower end is about 5wt. % higher than that at the upper end. In addition, the Al element shows an opposite trend, and the content of Al in the lower part of the alloy is significantly lower than that in the upper part (Fig.2a). More spherical tungsten-rich α-W phases are found in the lower part of the alloy ingot than in the upper part, which is also the reason for the higher W content in the lower part (Fig.2(b, c)). After the composition control of the alloy, the mass fractions of the upper and lower ends of the W element are 15.6 % and 15.9 %, respectively. And the mass fractions of the upper and lower ends of the Al element are 5.97 % and 5.93 %, respectively. Nearly no tungsten-rich α-W phases are observed in the alloy. The macro-segregation of W and Al elements has been significantly suppressed (Fig.2(d-f)).

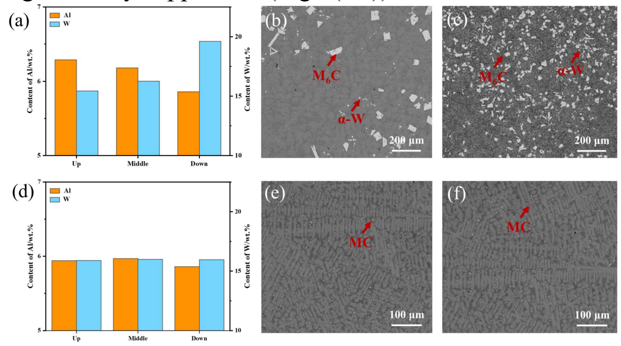

Fig. 2 The content of W and Al elements at different positions of ingot before and after element regulation: (a) before, (b) after; (b, c, e, f) microstructure at different positions

Conclusion

After controlling the alloying elements of Al, W and Ti, no tungsten-rich α-W phase precipitated. The macro-segregation of W and Al elements in the alloy ingot is suppressed, and the composition of the alloy ingot is uniform and the microstructure stability is enhanced.

References

[1] R.C. Reed, The superalloys: fundamentals and applications, 2006, Cambridge University Press.
[2] D. L. Shu, J. Xie, F. J. Zhang, G. C. Hou, Z. J. Wang, S. L. Xun, J. J. Yu, X. F. Sun, Y. Z. Zhou, Room temperature tensile deformation behavior of a Ni-based superalloy with high W content, China Foundry 18 (2021) 192–198.
[3] Q. Li, J. Xie, J. J. Yu, D. L. Shu, G. C. Hou, X. F. Sun, Y. Z. Zhou, Solidification behavior and segregation characteristics of high W-content cast Ni-Based superalloy K416B, J. Alloys Compd. 854 (2021) 156027.